Study on Icing Characteristics of Bundle Conductors Based on Xuefeng Mountain Natural Icing Station

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Abstract—**Icing on electric transmission line is one key factor which threatens the security and reliability of power grid. With wider application of bundle conductors in UHV or EHV transmission lines, however, there is no in-depth analysis of growth characteristics of icing on bundle conductors in the natural environment so far. Most researches are based on the methods of artificial simulation, which have big differences from engineering practice. In order to study the icing characteristics of bundled conductor, the icing tests on three kinds of bundle conductors have been done at Xuefeng Mountain Natural Icing Stations (XMNIS). Based on the testing results, this paper concludes: the growth rate of icing on windward site of conductors is faster than that of leeside, and the thickness of transverse direction is about ten times as much as that of lengthways direction; The growth of icing weight is nonlinear process, which is large at preliminary stage and saturated at last period; There is obvious stratification phenomenon in the icicles of hard rime, which is quite different from icing on short conductor in the artificial simulation experiments; Through the observation in the experiments, the ice shape, ice weight and ice thickness have no obvious differences among the single conductor, 3-bundle conductor and 4-bundle conductor. The conclusions can provide references for design and selection of overhead transmission lines in the region of hard rime.**

***Index Terms*—bundle conductor; icing; shape feature; ice thickness; ice weight**

I. INTRODUCTION

China is one of the countries in the world that has the most serious icing on transmission line[1]. Icing leads to mechanical and electrical properties of transmission line, which cause the ice accidents and have a strong impact on the security and reliability of power network. According to the incomplete statistics, the number of accidents has exceeded for 1000 times since there was a record of ice accidents on the transmission line[2]. In the period between January of 2006 and June of 2007, the number of 500kv line tripping caused by icing is 13, which is accounting for 8.84% of total line tripping [3]. The year of 2008 is the most memorable among recent years. Many areas in southern China have suffered extreme freezing natural disaster[4]. About 14 provincial power network and user from 570 counties are suffered varying influences. Over 100 of 220kV and above 220kv substation and hundreds of EHV line are outage in ice disaster. Icing on transmission line has been one key reason which influences the security operation of power network in the world.

With the accelerating pace of economic development and increasing of power requirement, bundled conductor has been a main style of erection in order to restrain corona development and reduce the line impedance, especially in the EHV and UHV[5]. Therefore, it is necessary to do further research on the characteristics of bundled conductor in icing environment.

The mechanism of ice accretion, formation conditions and the calculation method of ice and wind load are explored in the countries that have serious icing. Meanwhile, they have done significant research on icing protection. Research in [6] proposes that the temperature decide whether it can be iced, speed of icing and the types of ice. When conductors are in 0℃, the grow rate speed of icing is the fastest. Research in [7] shows that the growth rate of icing on transmission line has not totally direct ratio relations with wind speed. The speed of icing is fastest when the wind speed is between 3 and 6 meter per second. Research in [8-9] proposes that icing windward slope of mountains from east to west has a stronger icing degree than leeward slope. So far, researchers from domestic and overseas have studied many kinds of forecast model of ice, including empirical model from Lenhard [10], easy conceptual model from Goodwin [11], complex conceptual model from Makkonen [12],and numerical calculation model of freezing mixture between rime and glaze.

In order to pursue the natural character of bundle conductors, this paper chooses 3 kinds of conductors, including single conductor, 3-bundle conductor, and 4-bundle conductor, and conducts natural icing experiments at XMNIS. Characteristic parameters in the process of icing growth of hard rime are based on ice thickness, ice shape and ice weight. The key research point is the character of 3 kinds of bundle conductors in icing conditions, and compare with each other. Research results are a very important theoretical value for mechanism study of bundle conductor in rime and buildup of forecast model.

II. Test Platform, Samples and Methods

A. *Test platform*

XMNIS is located in Xuefeng Moutain of Huaihua City, Hunan province. The altitude is 1400 meters high. The icing station has typical micro-topographic climate and microclimate character. The period ice is between November and March in next year; the maximum of wind speed can reach 25m/s; annual precipitation is over 1800mm; the ice duration is as long as 50 days; the max ice thickness is above 500mm.The panorama of Xuefeng Mountain Natural Icing Station is shown is Fig.1.

Fig. 1 Panorama of Xuefeng Mountain Natural Icing Station

In the meantime, automatic meteorology is used to monitor the meteorological changes of the period of ice in real time, including wind speed, wind direction, temperature, humidity, air pressure and so on.

B. *Samples and Methods*

Samples are set up between two experimental towers in Natural Icing Station, and the line length is about 120 meters. Parameters of samples are shown in Tab.1. Characteristic parameters in the process of icing growth of hard rime are based on ice thickness, ice shape and ice weight. Ice thickness is measured by vernier caliper along ice growth direction of conductor, including the length of horizontal axis and vertical axis. Average is taken via multiple measurements. The procedures for measuring ice cross-section shape and ice thickness at the field station are summarized as follows. Firstly, an incision on the ice layer should be made, so the ice cross-section shape can be observed conveniently. Secondly, a hole with the same diameter as the conductor on the paper should be taken. And then, a channel from the edge of the paper toward the hole should be cut. The ice conductor through the hole on the paper should be inserted. Thirdly, sketch the outline of the ice layer on the paper. Finally, the area of the ice layer can be easily obtained using AutoCAD software based on the sketch. Ice weight is measured through cutting out ice on 1m of conductor.

Tab.1 Basic parameters of conductors

No	Types of wire	Diameter of wire(mm)	Material
1	single conductor	16.36	ACSR
2	3-bundle conductor	18.77/19.03 18.64	ACSR
3	4-bundle conductor	24.06/24.05 24.18/24.14	ACSR

III. Result and Analysis

A. *meteorological condition*

Portlog was used to monitor the meteorological changes of the period of ice in real time, including wind speed, wind direction, temperature, humidity, air pressure and so on. Based on the data acquired by automatic meteorology, the temperature at 19 o'clock on January 27th of 2015 was below zero, so this experiment regarded this moment as the beginning time and start to record the environment parameters in 120 hours of ice period. Temperature, dew point temperature, relative humidity, wind speed and wind direction in ice duration changed over time, and the changing curve is shown in Fig.2. As is shown in Fig.2(a), temperature and dew point temperature were always below zero in entire time. Temperature decreased with linear trend at the beginning. Temperature of third day fluctuated with day-night cycle, and fluctuation range had obvious increase with increasing ice time. When the ice time got 70 hours, temperature reached the minimum which was -7.5℃. Dew point temperature had the same trend with temperature. As is shown is Fig2(b), relative humidity was always too high, which kept 100 percent in most of time and its minimum value was 97 percent, which provided sufficient supercooled water droplets for ice of atmospheric structure. Fig2(c) shows that the wind was high at the beginning of ice, and it came to the maximum 7.7 m/s in the nighttime of January 28th. After that, it began to fluctuate with day-night cycle. Wind speed in the daytime and night were below 2 m/s and above 4m/s respectively. As is shown in Fig2 (d), wind direction was northwest or north in most of time, only southeast in the afternoon of January 29th, but the wind speed at that time was low.

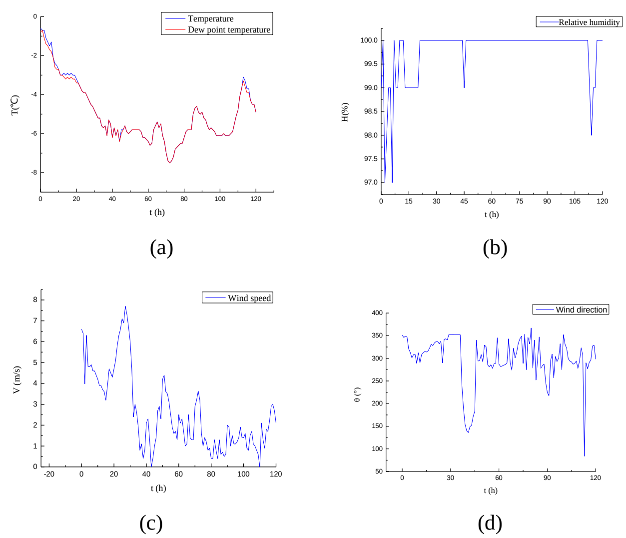


Fig. 2 Relationship between meteorological parameter and time

B. *Icing Characteristics of Bundle Conductors*

1、 *Ice thickness of Bundle Conductors*

In order to study thickness growth rule of bundled conductor, two axles were chosen to represent the thickness growth, which were horizontal axis and vertical axis respectively. As is shown in Fig.3, ice growth of horizontal axis was measured by the length of ice at windward side. Similarly, ice growth of vertical axis was measured by the length of ice at the direction which was perpendicular to the wind. As is shown in Fig.4 and Fig.5, conductor coated hard rime changed with time.

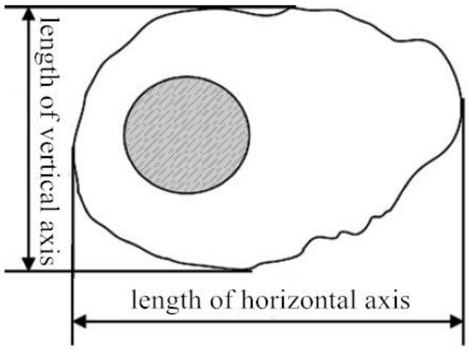


Fig. 3 Length of the horizontal and vertical axis

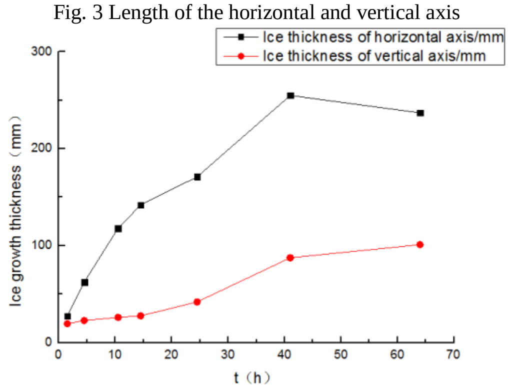
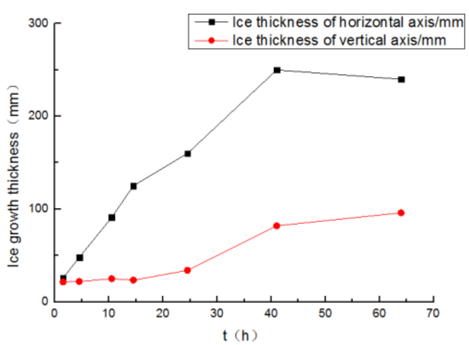
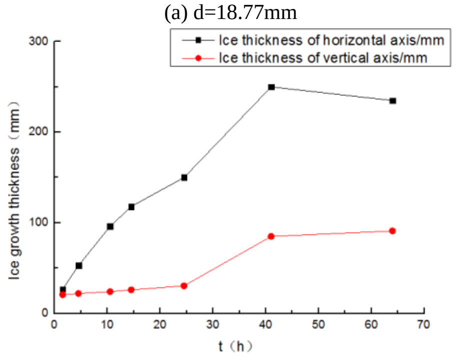


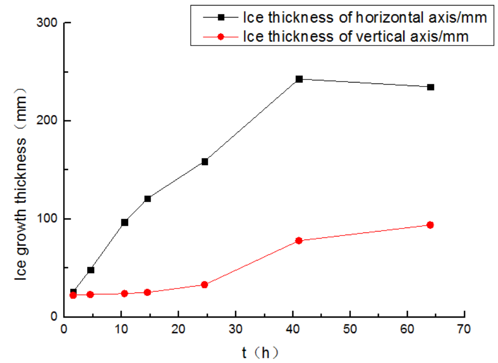
Fig. 4 Relationship between icing thickness of single conductor and time



(a) d=18.77mm



(b) d=19.03mm



(c) d=18.64mm

Fig. 5 Relationship between icing thickness of 3-bundle conductor and time

As is shown in Fig.4 and Fig.5, when comparing 3-bundle conductor with single conductor, there was no obvious difference in growth trend and ice process. Specific representation is shown as below:

(1) Growth speed of horizontal axis is distinctly different with which of vertical axis for both 3-bundle conductor and single conductor in the process of ice. This is because wind direction plays a decisive role in ice growth.

(2) The growth of ice thickness is a nonlinear process. In the first 15 hours of ice period, temperature of environment decrease sharply, and both humidity and wind speed are very high. In the meteorological condition, airflow with large numbers of supercooling water drop and conductor collide, water drop which is captured and stays on the conductor are freezing, thereby accelerating the rapid growth of ice on conductor.

(3) In the period between 15 hours and 41 hours, speed of ice decrease slightly but ice still grows with a certain speed. Because collision rate of water drop on surface of conductor changes with the increase of ice thickness. For the hard rime in this paper, ice thickness enlarges with the passing of time. When the sectional area on windward becomes bigger, viscous force in airflow makes component of the flow direction which is perpendicular to acceleration more bigger. Then distance of deviation movement is bigger, hence collision rate between small water drop and conductor decreases. However, windward area expands and decrement of collision rate is big, so some influence caused by decreased collision rate can be counteracted. After a period of time, with continuous thickness growth, collision rate rapidly decreases and icing speed is also lower accordingly.

(4) Ice period from forty-second hours, ice thickness of vertical axis increases slightly, while that of horizontal axis decreases slightly. This is due to twisting of conductor and further speed up the ice growth in direction of vertical axis, which decrease the ice growth in direction of horizontal axis accordingly. When the ice period approaches or exceeds 70 hours, ice on conductor reach saturation in direction of both vertical and horizontal axis. It can be seen clearly that the specific value of ice thickness between vertical and horizontal axis is above 5. The value in saturation is about 2.5.

(5) As in shown in Fig.5, No.1 and No.2 sub-conductor which in vertical direction had almost no difference. However, No.3 sub-conductor located in lee side was slightly lower than No.2

sub-conductor located in windward from the horizontal direction. It may be that wake flow of upper conductor may affect collision characteristics of lee conductor, resulting that ice on No.3 conductor was less serious. There was similar feature in 4-bundle conductor, which showed that ice growth in upper conductor is faster than lee conductor. However, there was no difference on ice thickness among all the sub-conductor in the period of saturation.

2、 Ice shape of bundle conductor

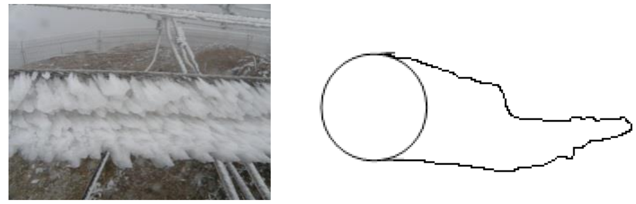
In order to study change of ice shape in bundle conductor, because there was almost no difference in ice shape among all the sub-conductors of 3-bundle conductor and 4-bundle conductor, one sub-conductor to state was chosen. As is shown in Fig.6, Fig.7 and Fig.8, icing morphologic change between multiconductor bundles and single conductor was basically the same in the process of icing.

(1)In initial stage, icing on windward of conductor was relatively uniform, but icing on lee side of conductor was rare, which was thin and nonuniform and even without ice in some places. This is because air offers glutinousness, which makes large numbers of water drops hamper windward of conductor, and turbulent vortex is formed at leeside. Momentum of supercooling water drop was bigger than that of airflow at windward of conductor, which made supercooling water drop separate from airflow and conductor collide, thereby form icing on windward of conductor.

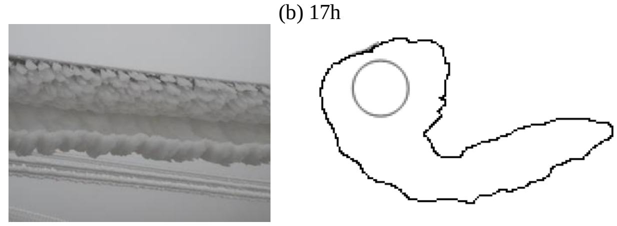
(2)Ice period from seventeen hours, ice on windward of conductor grows rapidly. There is layered phenomenon in ice, the length of which under layer is 3 times longer than that of upper layer. The reason: if the wind during that period didn't turn rapidly, ice thickness on windward would grow. When ice reached some thickness, the weight of ice was able to make the conductor twist, the phenomenon of stratification was found. Ice thickness on leeside also increased continuously, but the twist of conductor is limited, in comparison with ice on windward, that on lee side is still less. However, short conductor used for simulation in laboratory didn't have stratification in ice environment, for the 刚矩 of conductor is bigger than twist. This is an obvious difference between ice on practical transmission line and short conductor in lab.

(3)Ice period from forty-second hour, there was obvious dent in stratification of ice. The reason: ice under layer was influenced by air flow, and collision efficiency between small water drop and ice under layer increased, then ice thickness under layer obviously grew. Ice period over sixty-fourth hour, both ice under layer and ice on upper layer was thickened, and the dent of stratification was much deeper than before.

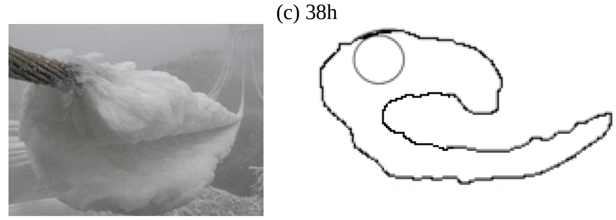
(a)10h



(b) 17h

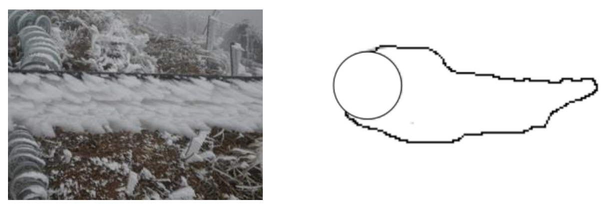


(c) 38h

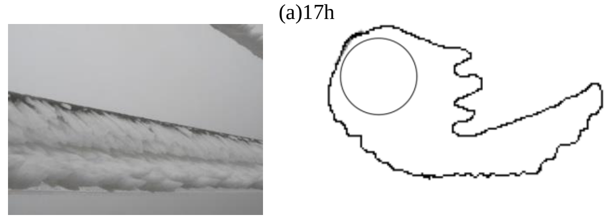


(d) 64h

Fig. 6 Relationship between ice shape of single conductor and time



(a)17h



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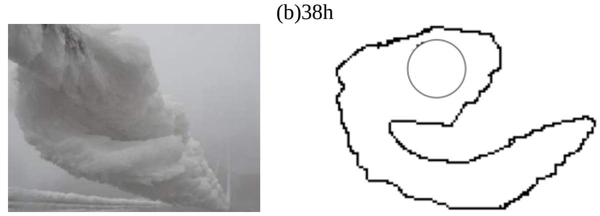
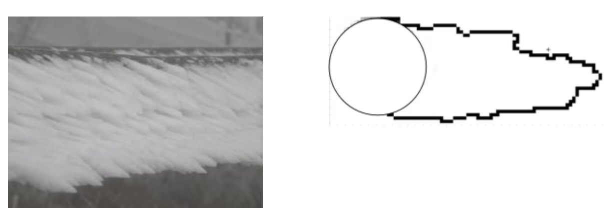
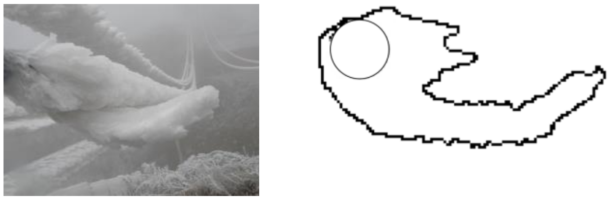


(c)64h

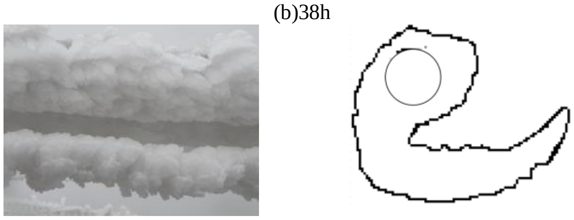
Fig. 7 Relationship between ice shape of 3-bound conductor and time



(a)17h



(b)38h



(c)64h

Fig. 7 Relationship between ice shape of 4-bound conductor and time

In order to study change of ice weight in bundle conductor, ice weight at the initial stages and metaphase grew fast, while it tended to saturation in later period for its light variation. As in shown in Tab.2, the difference of ice weight among 3 kinds of bundle conductors is quite small, which even can be negligible. The reason: the bundle conductors which has different diameter located in parallel position mainly influenced the initial stage of icing. When the icing in metaphase, both ice shape and area on windward were approached, and the ability to capture the supercooling water drop is same, so the ice weight at last almost had no difference.

Tab.2 Ice weight of bundle conductor

Types	Single conductor	3-bundle conductor	4-bundle conductor
Ice weight (kg/m)	5.8	5.83	5.93

IV. CONCLUSION

(1) Growth speed of horizontal axis is distinctly different with which of vertical axis for bundle conductor in the process of ice. The specific value of ice thickness between vertical and horizontal axis is above 5. The value in saturation is about 2.5.

(2) The growth of ice thickness is a nonlinear process. Icing on conductor at the initial stages and metaphase grew fast, while it tended to saturation in later period.

(3) When ice reached some thickness, the weight of ice was able to make the conductor twist, the phenomenon of stratification was found. While short conductor used for simulation in laboratory didn't have stratification in ice environment.

(4) Through the observation in the experiments, the ice shape, ice weight and ice thickness have no obvious differences among the single conductor, 3-bundle conductor and 4-bundle conductor.

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